PPO Resistance for Grain and Food Crops
A USA Perspective

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Topics

- Introductions
  - Where am I
- Overview of agriculture in USA
- Herbicide-resistance in USA
- PPO herbicides (Group 14 / E)
  - MOA
  - resistance
- PPO-resistance in my region of the USA
- Trends for the future
- Resistance management

New York City
Washington, DC
Recent DE Agric. Statistics

- Milha 75,000 ha
- Soja 80,000 ha (44,000 ha FSNT)
- Trigo and cevada 35,000 ha
- Vegetal (processo) 20,000 ha
- Vegetal (fresco) 6,000 ha
- Frango (carne) 252 million produced
Zonas de Robustez

Area Planted

<table>
<thead>
<tr>
<th>Crop</th>
<th>ha</th>
<th>%</th>
<th>Crop</th>
<th>ha</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>soja</td>
<td>32.1</td>
<td>24.9</td>
<td>arroz</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>milha</td>
<td>32.7</td>
<td>24.8</td>
<td>girassol</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>trigo (all)</td>
<td>22.1</td>
<td>16.8</td>
<td>canola</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>inverno</td>
<td>16.0</td>
<td>12.1</td>
<td>feijões secos</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>primavera</td>
<td>7.7</td>
<td>5.8</td>
<td>centeio</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>choqueira do feno</td>
<td>22.0</td>
<td>16.7</td>
<td>amendons</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>alfafa</td>
<td>7.2</td>
<td>5.5</td>
<td>beterraba</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>other hay</td>
<td>14.9</td>
<td>11.3</td>
<td>ervilhas secas</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>sorgo</td>
<td>3.4</td>
<td>2.6</td>
<td>batatas</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>algodão</td>
<td>3.3</td>
<td>2.5</td>
<td>vegetal (fresco)</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>cevada</td>
<td>1.5</td>
<td>1.1</td>
<td>vegetal (processo)</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>aveia</td>
<td>1.3</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Various populations have shown resistance to:

- Microtubule inhibitors (K1)
- Triazines (C1)
- Glyphosate (G)
- ALS-inhibitors (B)
- HPPD (F2)
PPO 14 / E Herbicides

- First commercialized in 1960’s
- Includes 9 herbicide families
- Can be used in annual crops, tree fruits/nuts, turf, and ornamentals
- Controls mostly broadleaf weeds
- "burning-type herbicide"

<table>
<thead>
<tr>
<th>Family</th>
<th>Diphenyl ethers</th>
<th>Diphenyl ethers</th>
<th>Diphenyl ethers</th>
<th>Diphenyl ethers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Ingredient</td>
<td>acifluorfen</td>
<td>fomesafen</td>
<td>lactofen</td>
<td>oxyfluorfen</td>
</tr>
<tr>
<td>Crops</td>
<td>soja soja soja</td>
<td>soja soja soja</td>
<td>soja soja soja</td>
<td>soja soja soja</td>
</tr>
<tr>
<td>Use Pattern</td>
<td>POST PRE POST</td>
<td>PRE / POST POST</td>
<td>PRE / POST POST</td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>none yes</td>
<td>yes minimal</td>
<td>yes rate</td>
<td></td>
</tr>
</tbody>
</table>

| Family                      | Triazolinones   | Triazolinones   | Phenyl-phthali- | Thiadiazoles   | Pyrimidine- |
|-----------------------------|-----------------|-----------------|nones |                | dienes     |
| Active Ingredient           | carfentrazone   | sulfentrazone   | flumioxazin     | fluthiacet     | saflufenacil |
| Crops                       | soja soja soja | soja soja soja | soja soja soja | soja soja soja |
| Use Pattern                 | POST PRE PRE    | PRE POST POST   | POST POST POST  |
| Residual                    | none yes yes    | none none none  | rate rate rate  |

PPO 14 / E Herbicides

- First commercialized in 1960’s
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Mechanism of Action PPO

- Inhibit chlorophyll synthesis
- Site of action is protoporphyrinogen oxidase (PPG oxidase or Protox)
  - an enzyme involved in chlorophyll synthesis
- Causes cell membranes to leak
- Herbicide requires sunlight but photosynthesis is not necessary

Mechanism of Action PPO

- Inhibit protoporphyrinogen oxidase (PPO)
  - an enzyme of chlorophyll biosynthesis
  - leads to accumulation of protoporphyrin IX (PPIX)
    - the first light absorbing chlorophyll precursor
- Light absorption by PPIX leads triple state PPIX and forms singlet oxygen
  - leads to chain reaction of lipid peroxidation
  - ultimately leaking membranes that allows cells and cell organelles to dry and disintegrate
Crop Plant Response

- Acifluorfen is metabolized in soybean by reduction => de-esterification => conjugation
- P450 involved with metabolism of sulfentrazone and carfentrazone

Can Cause Leaf Burn

PPO (E) Resistant Weeds

<table>
<thead>
<tr>
<th>Country</th>
<th>Species</th>
<th>Year</th>
<th>Additional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Euphorbia heterophylla</td>
<td>2004</td>
<td>+B</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Amaranthus hybridus</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Descurainia sophia</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Acalypha australis</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>Senecio vernalis</td>
<td>2014</td>
<td>+B, C1, C2, F1</td>
</tr>
<tr>
<td>Canada</td>
<td>Avena fatua</td>
<td>2015</td>
<td>nA, B, K3, N</td>
</tr>
</tbody>
</table>
### PPO (E) Resistant Weeds

<table>
<thead>
<tr>
<th>State</th>
<th>Species</th>
<th>Year</th>
<th>Additional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas</td>
<td>Amaranthus tuberculatus</td>
<td>2001</td>
<td>+B</td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td>2002</td>
<td>+B, C1</td>
</tr>
<tr>
<td>Missouri</td>
<td></td>
<td>2005</td>
<td>+B, G</td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td>2009</td>
<td>+B, C1, G</td>
</tr>
<tr>
<td>Iowa</td>
<td></td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>Indiana</td>
<td></td>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>Minnesota</td>
<td></td>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>Delaware</td>
<td>Ambrosia artemisiifolia</td>
<td>2005</td>
<td>+B</td>
</tr>
<tr>
<td>Ohio</td>
<td></td>
<td>2006</td>
<td>+B</td>
</tr>
<tr>
<td>Arkansas</td>
<td>Amaranthus palmeri</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>NC, TN, MS</td>
<td></td>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>VA</td>
<td>Eleusine indica</td>
<td>2013</td>
<td></td>
</tr>
</tbody>
</table>

### Resistance to Group 14 / E

- No reports of non-target sites
- Target-site resistance in *Ambrosia artemisiifolia* and *Amaranthus tuberculatus*
  - Codon of mitochondrial PPO was deleted in *A. tuberculatus*
  - Arg substitution for Leu for *A. artemisiifolia*
- Not as well understood as other MOA’s
Resistant Weeds in Delaware

- *Amaranthus hybridus* atrazine (C1)
- *Chenopodium album* atrazine (C1)
- *Amaranthus hybridus* ALS-inhibitors (B)
- *Ambrosia artemisiifolia* ALS+PPO-inhibitors
- *Coryza canadensis* glyphosate (G)
- *Coryza canadensis* paraquat (D)
- *Coryza canadensis* ALS-inhibitors +glyphosate (B+G)

Resistant Weeds of Note in the Region

- *Ambrosia artemisiifolia* glyphosate (G)
- *Lolium multiflorum* ACCase-inhibitor (A)
- *Sorghum bicolor* ALS-inhibitor (B)
Field with difficult to control *A. artemisiifolia*

*PPO-resistant *A. artemisiifolia* (Group E)

Not shown: carfentrazone, sulfentrazone acifluorfen, oxyfluorfen
A. artemisiifolia Population Response to cloransulam

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fomesafen 1, 2, 4X rates

glyphosate 1, 2, 4X rates

cloransulam 1, 2, 4X rates

**Glyphosate + cloransulam + fomesafen (all 2X rate)**

**Expansion of PPO-resistant Species**

<table>
<thead>
<tr>
<th>Trait</th>
<th>Amaranthus palmeri</th>
<th>Ambrosia artemisiifolia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-cycle</td>
<td>summer annual</td>
<td>summer annual</td>
</tr>
<tr>
<td>Flowers</td>
<td>dioecious</td>
<td>monoecious / imperfect flowers</td>
</tr>
<tr>
<td>Competitiveness</td>
<td>very high</td>
<td>high</td>
</tr>
<tr>
<td>Height</td>
<td>&gt;1.7 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Stress-tolerant</td>
<td>very high</td>
<td>fair to good</td>
</tr>
<tr>
<td>Roots</td>
<td>weak taproot</td>
<td>fibrous</td>
</tr>
<tr>
<td>Emergence pattern</td>
<td>very long</td>
<td>short (early spring)</td>
</tr>
<tr>
<td>Seed production</td>
<td>&gt;1 ml</td>
<td>&gt; 50,000</td>
</tr>
<tr>
<td>Seed longevity</td>
<td>3-4 yrs</td>
<td>3-4 yrs</td>
</tr>
</tbody>
</table>
Weed Management Programs

- **plant into a clean seedbed**
  - use tillage or an effective burndown herbicide for no-till;
- **use an effective soil-applied herbicide program** shortly before or at planting;
- **use multiple herbicide sites of action**
  - herbicides need to be **EFFECTIVE** not just different
  - consider herbicides sprayed previous year and what will be used in coming years;
- **never apply glyphosate by itself when species prone to resistance are present;**
Weed Management Programs

- Postemergence applications must be made to small (less than 8-cm) plants;
  - If PRE herbicide is used this is typically 3 to 4 weeks after planting
- Need to conserve some herbicide groups for vegetables and small grains;
  - Consider not using some herbicide groups where other options exist
  - Avoid use of ALS inhibiting herbicides (Group B) outside of vegetables, small grains, and soybeans
  - Avoid use of PPO (Group E) outside of soybeans and vegetables
- AND limit weed seed production of problem species

Rotations Are A Large Part of Weed Management

Following comments are assuming crop rotations

- Continuous corn or soybeans OR two-yrs back-to-back may require different approaches

Increasing Use of PPO's

Soja
- saflufenacil
- sulflentrazone
- flumioxazin
- fomesafen
- acifluorfen
- carfentrazone
- fluthiacet
- lactofen

Milha
- saflufenacil
- carfentrazone
- fluthiacet

Others
- oxyfluorfen
Heavy Rye Cover Provides 65 to 95% Control

Rye Cover Crop
No Cover Crop

Sources

Any QUESTIONS?